OPTIMIZATION OF COOLING CHANNEL PARAMETERS FOR DESIGNING THREE PLATE MOULD OF HEXAGONAL FLOOR TILE USING TAGUCHI METHOD TO REDUCE WARPAGE

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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Manufacturing.

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ABSTRACT

This project deals with optimization of cooling channel parameters for designing three plate mould of hexagonal floor tile using Taguchi method to reduce warpage. The objective of this project is to analyze the hexagonal floor tile design by simulation with Moldflow Plastic Insight software (MPI) and to optimize the mould design parameter using Taguchi method. The product is designed in hexagonal shape build with interlocking features and will be used for application in indoor sports activities such as futsal, badminton, takraw and other sports. The material used for this design is thermoplastic elastomer (TPE) that increased the slipping resistance due to active and fast movement on it. The design of the product will be analyzed using MoldFlow Plastic Insight software (MPI) to reduce the warpage problem that appears during injecting the product. Warpage is the deflection of the part on the product design from its original shape. Taguchi method is used to optimize the parameter of the mould design for injecting the product with less warpage. In addition, the signal to noise ratio and analysis of variance is utilized to optimize the parameter for the product. The Taguchi method is conducted to minimize the warpage in both +z deflection and -z deflection. The result shown that, the most significance parameter of the mold design that tend to minimized the warpage values are from the cooling channel diameter at cavity half, cooling channel distance at core half and cooling channel diameter at core half. Also, from the result the summarized of the mold design parameter that reduces the warpage problem has been identified for the further process which is fabrication of mold.

ABSTRAK

Projek ini membentangkan tentang kaedah mengoptimumkan parameter sistem penyejukan untuk reka bentuk acuan plastik jenis tiga kepingan bagi produk jubin lantai plastik heksagonal. Objektif tesis ini adalah untuk menganalisa produk jubin lantai plastik heksagonal dengan menggunakan perisian Moldflow Plastic Insight (MPI) dan juga untuk mengoptimumkan parameter reka bentuk acuan plastik dengan menggunakan kaedah pengoptimaan Taguchi. Reka bentuk produk tersebut telah direka dengan sistem 'interlock' pada setiap luaran jubin plastik yang membolehkan pemasangan lebih cepat dan mudah. Produk jubin plastik ini sesuai diaplikasikan pada aktiviti sukan seperti futsal, badminton, takraw dan juga sukan lain. Bahan yang digunakan untuk produk ini adalah daripada thermoplastic elastomer (TPE), bahan ini sesuai digunakan kerana ia mempunyai sifat tahan kepada gerakan yang dapat mengelakkan pengguna daripada tergelincir. Produk ini dianalisa menggunakan perisian MPI untuk mengoptimumkan kadar pengurangan masalah pemeledingan semasa proses pembuatannya. Pemeledingan adalah proses pembengkokan reka bentuk produk daripada bentuk asalnya. Untuk mengatasinya, kaedah Taguchi digunakan untuk mengoptimumkan parameter untuk reka bentuk acuan agar proses pancutan dapat menghasilkan produk yang kurang masalah meleding. Justeru itu, kadar nisbah isyarat dan bunyi serta ANOVA analisis digunakan untuk mengoptimumkan parameter untuk produk tersebut. Kaedah pengoptimaan Taguchi digunakan untuk meminimakan pemeledingan dari arah +Z dan –Z. Hasil analisis itu telah menunjukkan bahawa parameter yang paling mempengaruhi proses meleding adalah garis pusat saluran penyejukan di rongga acuan, jarak saluran penyejukan di teras acuan dan garis pusat saluran penyejukan di teras acuan. Hasil parameter yang mengurangkan proses meleding telah dikenalpasti dan diringkaskan untuk proses akan datang iaitu proses pembuatan acuan.

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LIST OF SYMBOLS

O_1	Start diameter of sprue bush
O_2	End diameter of sprue bush
L	Length of sprue
η	Signal to noise ratio
Y_i	Value of warpage for *i*th test
n	Number of test
f_T	Total degree of freedom
N	Total number of simulation result
f_A	Degree of freedom due to factor A
K_A	Number of level due to factor A
S_T	Total sum of squares
Z	Analysis result value
S	Sum of square
Mq	Mean sum of square
F	F- ratio value
S_e	Sum of square due to error
Sq'	Pure sum of square
Mq_e	Mean sum of square due to error
P	Percentage of contribution

LIST OF ABBREVIATIONS

CAE	Computer aided engineering
MPI	Moldflow Plastic Insight
TPE	Thermoplastic elastomer
ANOVA	Anlaysis of variance
CAD	Computer aided design
S/N	Signal to noise
M.S.D	Mean square deviation

CHAPTER 1

INTRODUCTION

INTRODUCTION

This chapter is arranged in the following manner. Section 1.1 gives an overview of the project background, section 1.2 presents the objectives of the project and section 1.3 presents the scopes of project while section 1.4 describes the problem statement of the project.

1.1 PROJECT BACKGROUND

Nowadays, injection moulding product has been extensively used in the daily application such as for household appliances, industry field and also in the sport equipments. Formerly known, the plastic material has advantages such as lower in cost and light in weight compared to other material which also being used for such applications. In this project, the focus is on the application of sport which is for the sport courts. Plastic material is widely used in the equipment of sport but not in the used for sport courts. Mostly, the sport users want the sport court to give good grips to their movement. The desired to get such function has been developed the idea to introduce the plastic material to be used in the sport court application.

This project is to produce a floor tile which can be used for the indoor sport activity such as futsal, badminton and other sports. The floor tile product will be produce by using the thermoplastic as the material and the product design will be in the

hexagonal shape which comes out with the interlocking features for the attaching purpose. In achieving to the goal for creating a plastic floor tile, the processing method will be carried out in the injection mould machine. Therefore, the mould of the product must be design in order to injecting the plastic floor tile.

In order to ensure the mould design will produce a fine injection product, an approach method is undertaken to optimize the mould design parameter that is by using the Taguchi optimization method. The value of parameter used in the optimization method is utilized from the CAE software which is Moldflow Plastic Insight software (MPI).

1.2 OBJECTIVE OF PROJECT

1.2.1 To analyze the hexagonal floor tile design by simulation with Moldflow Plastic Insight Software (MPI).

1.2.2 To optimize the mould design parameter using Taguchi optimization method.

1.3 SCOPE OF PROJECT

The general scopes of this project that need to be focused are:

1.3.1 Determination of the main cause and factors that influence in producing warpage defect

1.3.2 The material used is Thermoplastic elastomer (TPE) which gives desired mechanical properties.

1.3.3 The analysis in Moldflow Plastic Insight software (MPI) is based on 3 plate mould type.

1.3.4 Determination of suitable orthogonal arrays and used smaller the better analysis.

1.3.5 Identified the optimum condition of parameter that minimizes the warpage.

1.4 PROBLEM STATEMENT

In every injection moulding process, the problem after the plastic melt turns to solid is the main undesirable consequence for the product to be made. In fact, the product design for this project is a flat shape design which the product warping is the major problem needs to be concerned. Since the modification for the injection product is irrelevant for reducing the warping problem, the attention should be put before injecting the product that is during the designing and analyzing process for the product design. Also, it is complicated and hard to determine the exact value of the parameter in the injection moulding. It is important to determine one method to get the best result so that for future mould fabrication of this product produce minimize warpage.

CHAPTER 2

LITERATURE REVIEW

INTRODUCTION

This chapter is arranged in the following manner. Section 2.1 describes about mould components, section 2.2 presents the feed system, section 2.3 describes the thermoplastic material and the last section 2.4 describe about the Taguchi technique.

2.1 MOULD COMPONENTS

The injection moulding is one of the most important methods applied for polymer plastic processing operations in the plastic industry. The injection moulding product has improved the old trend part processing such as die casting since the plastic product gives many advantaged in terms of surface finish, weight and cost reduction.

The process of injection moulding can be described shortly in which the plastic material is heated first in the barrel to its melting temperature. Then, the plastic melt is injected in the cavity of the mould with high pressure. The cavity in the mould has the dimension and shape of the desired product. When filling stage is completed, the cavity is kept under a constant pressure for packing pressure take place.

There are two main type of mould design that is two plates and three plate mould. The different between both type is the two plate mould have only single parting line while the three plate mould have double parting line. The top plate is the part in the

mould components that are stationary and this plate will be clamped to the fixed platen of the injection machine. This part consists of locating ring, sprue bush and eye bolt. Locating ring is a component in top plate used to prevent the unmatched nozzle of injection machine. Locating ring is selected by considering the sprue bush design so that the locating ring not smaller than the sprue bush diameter. In designing the sprue bush, the diameter of the ball in the sprue bush must not too smaller than the nozzle diameter to prevent working plastic flash.

There is an addition plate in the three plate mould that is runner stripper plate. This plate used to cut the plastic resin between the sprue bush and the runner. The cavity plate consists of the hollow part which represents the product design to be produced. In three plate mould type, the cavity plate is divided into two that are fixed cavity plate and moving cavity plate. The fixed cavity plate will hold cavity side and the moving cavity plate or male plate used to attach the core side.

Also in this part also hold an important part that is cooling system. Beside the cavity plate is the support plate, this plate used to attach the return pin's spring. The return's spring is used to relocate the plate after ejection of the injection product. The bottom plate is used to support the spacer block, hold the cavity and the ejection system like puller and this plate is attached to the movable platen in the injection machine. Shown in Figure 2.1 is the basic construction of three plate mould in which this type of mould will be used in the Moldflow software.

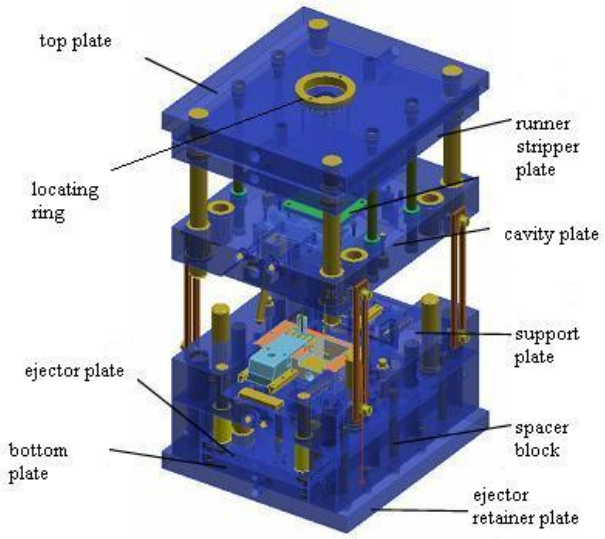

Figure 2.1: Three plate mould components

Source: http://mould-technology.blogspot.com

2.2 FEED SYSTEM

A feed system consists of sprue bush, runner and gating system. The feed system used to deliver the plastic melt into the cavity of the mould. Sprue bush which is locating at top plate of the mould can be design using the design consideration. While runner divided into two types which are hot runner and cold runner. In hot runner mould, the plastic melt stay in liquid forms while the cold runner solidified and need to proceed with the extra process such as cutting. In doing this project, the cold runner system is used since it is less costly for the future mould fabrication.

Mostly, the sprue bush is design from the manufacturer with standard dimension depending on the nozzle type of the injection mould machine. Usually, the sprue bush is design in ½ inch or ¾ inch in radius. It is design in tapered dimension for easily remove of resin from the sprue bush in the ejection stage of injection moulding process. The dimension of the sprue bush is based on the equation 2.1 where start diameter of sprue bush is denoted as O_1 and the end diameter of the sprue bush is denoted as O_2 and length denoted as L. Shown in Figure 2.2 is the figure of the sprue bush.

$$O_2 = O_1 + L\ (Tan\ 2.386°) \qquad (2.1)$$

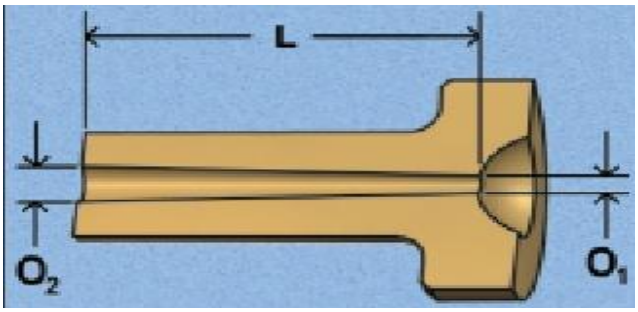

Figure 2.2: Sprue bush illustration

Source: Injection Mould design guideline by Dr. Paul Engelmann and Bob Dealey (1999)

Since the design of hexagonal plastic floor tile is large and for single cavity, the suitable type of gate is the pin point gate. This type of gate is design by locating the gate at the top surface of cavity half. The gate must be design small in shape for ease of cut of the gate. A sprue gate can be used for single cavity but it also must depend on the mould type. In this project, the Moldflow simulation is based on three plate mould and the pin point gate is the best gate type to be applied.

2.3 THERMOPLASTIC MATERIAL

Thermoplastic material is one of material that can be used in the injection moulding process. Thermoplastic elastomer (TPE) is one of the thermoplastic materials that have been extensively used in any plastic industry these days. This type of material has properties such as soften feature, flexible and also stiffness and lower in density. The material properties of the thermoplastic material (TPE) are shown in Table 2.1.

Table 2.1: Material properties of thermoplastic elastomer (TPE)

Material properties	
Melt density	0.76922 g/cm^3
Mould temperature	40 °C
Melt temperature	230 °C
Shear modulus	2.79 MPa
Poisson rate	0.38
Material structure	Crystalline

Source: Moldflow Plastic Insight software (MPI)

Utilizing the packing pressure is needed to fill the remaining volume of the cavity and to reduce shrinkage due to cooling. This shrinkage can be one of the factors for the warpage problem occurred. Warpage can be occurred from the flow orientation when injecting the part in which the orientation of flow leads to directional shrinkage variation.

Differential cooling also contributes in producing warpage by the result in variations in sectional shrinkage. The temperature between core half and cavity half of the mould will cause differential shrinkage which the shrinkage increased the tendency to have bending moment after part is ejected from the cavity. Depending to the mechanical properties of the material selection, this bending moment created warpage or residual stress to the part [1].

A cooling system is used to lowering the temperature of the mould and also help to solidify the plastic melt in the cavity. Given by D.E Dimla et al [2], a better cooling system design must allow the cooling fluid to transfer the heat by circulating action. A new gate can reduce the tendency for part shortage but previous study given by D.E Dimla et al [2], increasing number of gate will not improve the cooling time and tends to make designer to create complex cooling system design.

In the injection process, although the high temperature is considered for the easier flow of the plastic melt into the cavity, the increase in temperature also will bring other consequence as found by A. Demirer et al [3] which state that The increasing temperature will lead to increase warpage generally. Therefore, as the injection pressure increase, the percentage of the shrinkage can be reduced. Also, the residual stress also need to observe since the previous study by C.H Kim [4] found that residual stress can cause warpage to the product due to non-uniform temperature profile.

It is very important to get the desire product with a good quality and in order to get the desired specification, the good cooling channel that provide cooling fluid must be obtained systematically. From the previous study given by D.E Dimla et al [2] state that different cooling channel requirement is needed for different physical effect. The cooling channel must be built in the side of the convex area rather than the concave area because the convex area tends to have concentration of heat.

Also, from this study state that a better cooling system design must allowed the cooling fluid to transfer the heat by circulating action. In our context area, the cooling channel must be balance as the design injection mould product have same thickness and not have either convex or concave properties. Figure 5 shows the example of cooling design in Moldflow Plastic Insight software.

Figure 2.3: Cooling system design in Moldflow software
Source: B. ozcelik et al (2005)

2.4 DESCRIPTION OF TAGUCHI TECHNIQUE

Taguchi technique has been developed by Taguchi and Konishi. This technique is a wide range of range of experimental techniques to dramatically improve process and product characteristic. The principals of Robust Design are based on many ideas from statistical experimental design. They are used to plan experiments for obtaining information about variables involved in making engineering decisions.

The philosophy of Taguchi method is broadly applicable. He proposed that engineering optimization of a process or product should include system design, parameter design and tolerance design [5].

System design requires technical knowledge and extensive experience in area of specialization to initially design or specify the process or product. System design does not utilize design optimization methods such as the design of experiment.

Parameter design provides a means of both reducing cost and improving quality by making effective use of experimental design methods. This involved of determination of parameter values that are least sensitive to noise. Parameter design is most important step when the goal is to design a process or product with high stability and reliability. The objective of the parameter design is to optimize the settings of the process

parameter values for improving performance characteristics and to identify the product parameter values under optimal process parameter.

Tolerance design is a means of controlling factors that affect the target value by using higher grade components and inevitably increasing the cost. After the system has been design and the parameter is determined, the next step is to set the tolerance of the parameters. At the tolerance design stage, the noise factors are controlled by keeping them with narrow tolerances.

Some researchers have performed to optimize the optimum levels of parameters based on orthogonal arrays experiments of Taguchi's throughout injection moulding of plastic components. In 1995 [6], Metrol used Taguchi methods together with finite elements method to investigate the optimal dimension for plastic pin ball grid array. Chien and Shiou [7] have studied for determining the optimal process parameter depended on Taguchi orthogonal array in finish operation of a freeform surface plastic injection moulding.

CHAPTER 3

METHODOLOGY

INTRODUCTION

This chapter is divided in several sections that are section 3.1 for product design, section 3.2 describes the pre-analysis of product design .The next sections which are section 3.3 presents the analysis of experimental data and section 3.4 which describes analysis of variance (ANOVA). This chapter shows the sequence of method that has been utilized in doing this project.

3.1 PRODUCT DESIGN

In this project, a product design must be modeled before proceed with performing the Moldflow software and lastly optimizing it using the Taguchi robust design method. The product design in this project is a plastic floor tile used for sport activities purpose. Basically, the product design is in a hexagonal shape and will apply the concept of interlocking plastic tile. The concept of interlocking tile brought by this product will make the tile applying and removing process much ease than conventional tile. Furthermore, this concept will not damage the interface of the basis floor compared to the conventional tile which need permanent joint such as cement.

Since this project is to create a plastic tile for the injection molding product, the product design needs to consider the requirement for the mold design. Even though the mold design must essentially the same as the product shape and dimension, the product